Proceedings of 14th IOE Graduate Conference
Peer Reviewed
Year: 2023 Month: December Volume: 14
ISSN: 2350-8914 (Online), 2350-8906 (Print)

Numerical Analysis of Embankment Constructed above the Soft Soil with Different Improvement Measures

Bigyan Adhikari [a], Indra Prasad Acharya [b]

[a,b] Department of Civil Engineering,Pulchowk Campus,IOE,Tribhuvan University, Nepal
[a] 078msgte003.bigyan@pcampus.edu.np, [b] indrapd@ioe.edu.np

Abstract

To simulate the behavior of different improvement measures such as basal geogrid, ordinary stone column, geogrid encased stone column in soft soil below embankment, three-dimensional finite-element analysis (FEA) were employed. For a given set of soft soil and stone column parameters, numerical analyses were performed by altering the length, diameter, center to center spacing of the stone column, tensile stiffness of the geogrid encasement and length of the geogrid encasement.The findings of the FEA has been demonstrated that in shallow soft soil layers, the influence of the geogrid encasement in combination of basal geogrid increased the global factor of safety of embankment by 57.26% (1.17 to 1.84), vertical settlement reduced by 67% (from 235.92mm to 78.05 mm), lateral deformation reduced by 93% at top & by 96% at the bottom of encasement of stone column, it was also found that in comparison to ordinary stone columns, the encased stone columns bears a larger total vertical stress. The stone column's encasement results in a higher reduction of the total vertical stress of the adjoining soil. Current study conclude that even the diameter and length of the drainage paths are the same for conventional and encased stone columns, the encased columns further reduce the development of excess pore water pressure and fasten its dissipation. The goal of the current research is to better understand how a basal geogrid reinforcement, ordinary stone column and the stone column encased with geogrid behaves.

Keywords

Basal reinforcement,Finite element analysis, Geogrid encasement,Soft soil,Stone columns,

1. Introduction

The governing criteria for carrying out any construction activities is the actual site conditions. The structure should be designed based on the characteristics of the soil, to meet the design requirements of the structure, the soil should be enhanced. Soft clay are highly plastic fine grained soil characterized by high compressibility and low shear strength, clay for which unconfined compressive strength less than 50kPa are soft clay and clay with unconfined compressive strength less than 25kPa are classified as very soft similarly the cohesive soil with observed standard penetration resistance value during standard penetration test 2-4 marked as soft soil [1]. Due to their poor bearing capacity, excessive compressibility, propensity for lateral flow some problematic soils, such as soft clay deposits, peat soils, recent fills, marine clays, etc provide difficulties in building any infrastructure above it. To improve these grounds engineering behavior in accordance with the structure's design specifications, treatment is required. There are varieties of method of soil improvement provisions such as filling with lightweight materials, preloading or surcharging, provision of vertical drains, excavation and replacing the existing soil, provision of columns, provision of reinforcements in foundation soil, stage-wise embankment construction, use of in-situ admixture in foundation soil or in embankment construction and many types of ground improvement techniques have been proposed to improve the ground, based on cost, time and in-situ requirements [2]. Arrangement of either prefabricated vertical drains, lime cement columns or lime cement columns with prefabricated vertical channels are successful to diminish the settlement of establishment soil underneath the embankment. Be that as it may, among all these, arrangement of lime cement columns beside prefabricated vertical channels is the foremost compelling procedure to diminish the settlement at all the time interim amid and after the development of embankment. All the three strategies are moreover viable to quicken the solidification prepare, but the lime cement columns with punctured vertical channels are most viable, taken after closely by perforated vertical channels to scatter overabundance pore water weight. The lime cement columns given independently are in any case slightest compelling to disseminate abundance pore water weight [3].

Soil cement columns are effective to diminish the settlement compared to short soil cement columns, long soil cement columns are effective as it were to move forward the settlement and not much effective to progress the figure of factor of safety [4]. Among of them the construction of stone columns is a popular method for addressing soft clay soil & it consist of partial replacement of unsuitable sub surface soil with a compacted vertical column that generally completely penetrate the weak strata stone columns have advantages such as enhanced stiffness, decreased settlements, increased time rate of settlements, greater shear strength, and decreased propensity for soft ground to liquefy.When quick construction and little deformation are required, the use of geosynthetic reinforcement at the base of the embankment coupled with stone columns offers an affordable and practical alternative. Stone columns placed beneath embankments strengthen stability, decrease excessive settlement, and raise the bearing capacity of soft foundation soil. Geosynthetic reinforcement helps transfer pressures from soft soil to stone columns and lowers maximum and differential settling. Various numerical studies had been conducted in recent decades for the improvement of soft soil below the embankment[1]. The remarkable improvement in the lateral deformation of the column over its length, generation, and dissipation of excess pore pressure, settlement and found increase in the factor of safety by 53% using the encased stone column in comparison with untreated soil similarly the failure surface changes from deep seated failure to face failure[4]. Due to the lack of lateral confinement resulted in substantial bulging, which rendered conventional stone columns useless for holding the embankment the soil layer is designed the 3D strip and strip width taken as 2 m [4]. The design technique adopted for soil layer is using the unit cell concept and 3d strip concept[5].For preventing excessive lateral spreading, basal reinforcement is important. Higher the encasement stiffness lesser will be the horizontal displacement, horizontal displacement decreased by 56% when using the encasement of 4000kN/m stiffness[1].

According to parametric analyses, the improvement in the geosynthetic encasement's ability to lessen settlement increases with decreasing soft-soil thickness. Additionally, it was found that for geosynthetic stiffness greater than 2000 kN/m, the influence of the geosynthetic on settlement gradually decrease[6]. Typically, the column's lateral bulging is at its highest level at a depth close to its diameter. Beyond that, the bulging values gradually diminish until the base value is zero. With increased weight, the stone column bulges more, transferring greater stress during consolidation to the lower depths. The stone column is well contained, its bulging is lessened, and the lateral deformations are more regular along its height when it is enclosed. By creating radial tensile forces in the geogrid encasement, the encasement increases the lateral support of the stone column and improves the stress transmission with depth. Even if the diameter and length of the drainage paths are same for conventional and encased stone columns, the encased columns further reduce the development of excess pore water pressure and fasten its dissipation. This effect results from the enclosed stone columns being more rigid overall, which increases the amount of stress that is transferred from the surrounding earth [7].

The stone column's encasement also results in a higher reduction of the effective stress in the nearby soft soil. This is due to an increase in stress transfer from the surrounding soil caused by the encasement's increased stiffness of the stone columns as a whole [7]. The ground improvement using stone column technique had been studied and implemented in the construction sector in case of nepal in rare amount in the past and it is increasing day by day.Ground improvement using geogrid encased stone column for the construction of embankment specially road embankment will be the new case from the view point of research and implementation in case of terai region soft soil. One of the key sector of research is the evaluation of effect of different design parameters on functioning of different improvement measures such as basal geogrid, ordinary stone column and geogrid encased stone columns and helps to understand their behavior on different conditions so there is essence for the study of different parameters such as diameter, length, center to center spacing, encasement length, axial stiffness of encasement properties of stone column to be used and the other parameters on the factor of safety, vertical settlement, lateral deformation, excess pore pressure, vertical stress distribution pattern of soil improved by different improvement methods such as basal reinforcement, ordinary stone column and geogrid encased stone column. This will also help for the study of usefulness of GESC (Geogrid encased stone column) in our geological setting and its effectiveness.

2. Study area

The study area is the Pakali-Kanchanpur road section of East West Highway and the data of the particular chainage of that road section comprising with top soft soil layer is considered for study and analysis, the Pakali lies in the Sunsari District and Kanchanpur lies in Saptari district of Southern Terai the country's southern region has been traversed by the road alignment. The Indo-Gangetic Plain and Siwalik mountains enclose the southern region. The road layout thus follows the Genetic Plain sediments. The Bhabar, Middle Terai, and Gangetic Plains are divisions of the plain. Using the geomorphology, describe the southern Terai from north to south. In the Bhabar region, comprised of sand, cobble, and boulder. The marshy land of the middle Terai consists of cobbles, sands, silts, and clay are also present. The southern Terai is distinguished by the silt and clay [8].

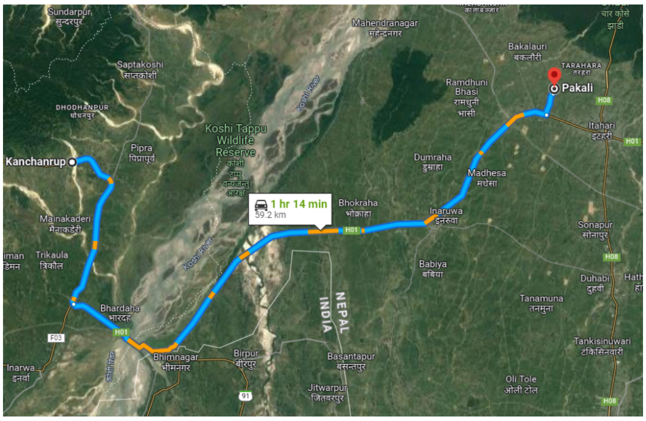

Figure 1: Study area of the research

3. Methodology

The data necessitates for the numerical analysis were taken from the bore hole logs recorded at the various chainage of Pakali-Kanchanpur road section as described in study area and their laboratory test and analysis. The analysis was performed using finite element approach considering the 3D modeling.

3.1 Finite element model

For the purpose of numerical analysis parametric study of different improvement measures including geo-grid encased stone columns technique is adopted for study the improved situations. For this first the soil were modeled creating a borehole and after that the structural component of model were defined, for the reduction of calculation time symmetry of the axis of the model has been considered and one half of the embankment structure and the corresponding soil layer is

Table 1: Material properties and model used during the analysis

Parameters	Embankment	Granular Blanket	Clay	Sand	Stone Columns	Geogrid
Thickness/Depth(m)	5	0.5	4.5	12		
Material Model	Hardening Soil	Hardening Soil	Soft Soil Model	Hardening Soil Model	Mohr-Columb	Linear Elastic
Drainage Type	Drained	Drained	Undrained	Drained	Drained	
Soil Unit Weight Below Pheratic Level $\Upsilon_{sat(}$kN/m^3)	28	19.5	17.88	21.21	20	a.Mass Per Unit area(gm/m^2)=240 b.Axial Stiffness at 2%Strain(Kn/m)=800 c.Aperture Size(mm*mm)=31mm*31mm d.Thickness 1.94mm e.E=97*10^3 Kpa During Parametric Analysis Stiffness will be vary 800 to 4000 kN/m
Cohesion C'(kN/m2)	0	0	18.62	-13.72,Upto 6 m depth -12.74,Below 6 m depth	0	
Modulus of Elasticity E'(kN/m^2)	50*10^3	15*10^3	4*10^3	15*10^3	80*10^3	
Friction Angle Φ'(Degree)	38	33	3	-16,upto 6 m depth 19,below 6 m depth.	40	
Dilatancy Angle Ψ(Degree)	0	0	0	0	5	
Horizontal Permeability K_h(m/s)	4.05*10^-5	8.2*10^-5	8.8*10^-7	3*10^-5	10	
Vertical Permeability K_v(m/s)	4.05*10^-5	8.2*10^-5	5.6*10^-7	2.8*10^-5	10	
Poisson's ration ν	0.3	0.3		0.3	0.3	
Modified Compression Index λ*(-)			0.03			
Modified Swelling Index K*(-)			0.019			

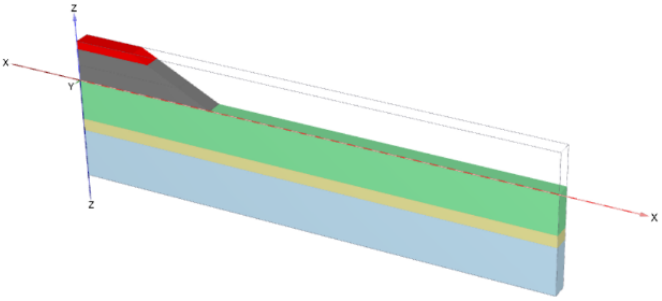

Figure 2: 3D-Model

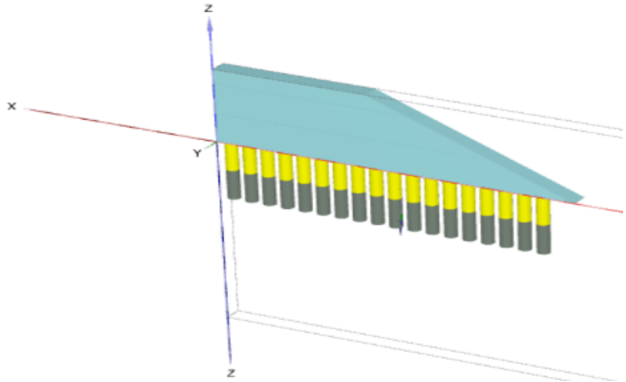

Figure 3: Structural Model

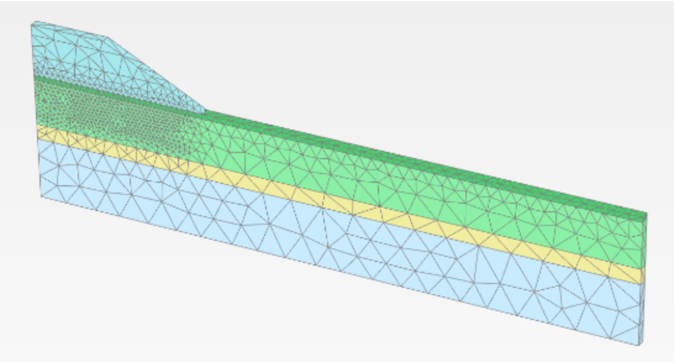

Figure 4: Finite element mesh with embankment

modeled. The dimension of the embankment being 35m width with 15m top width and the height of the embankment being 5 meter, only half of the embankment dimension is considered so the dimension of embankment model is 17.5 meter width with top width of 7.5 meter and the length of the embankment is considered as the strip width equals to the center to center spacing of stone column. The number of stone column were determined from the assumed center to center spacing between stone column. The diameter of stone column (d) adopted were 0.6m, 0.8m and 1m the center to center spacing of stone column used were 1.5d, 2d and 3d, the thickness of granular blanket taken as 0.5m and the thickness of the strip width taken for modeling equals to the center to center spacing between the stone columns. The stone column length is taken as 4 meter and encasement length is 2m for 0.6m diameter stone columns, similarly stone column length is 6m and encasement length is 3m for 0.8m diameter stone column and stone column length is 8 meter and encasement length is 4m for stone column of 1m diameter. The lateral extent of the model were also considered 60m in order to avoid any influence of the outer boundary 10 noded tetrahedral elements were used to carryout 3d modeling of embankment and stone column. The boundary fixity is as default of plaxis the 3d model is shown in figure 2 and 3.

3.2 Input parameters and material models

Input parameters and material models are shown in table 1.

3.3 Stage construction and node selection for calculation

Embankment layer is constructed in sequence of 2m, 2m and 1 m of stage providing the 2, 12days, 2, 10 days and 1, 5 days for construction and consolidation for each layer. There are altogether 32 phase created for calculation of different parameters considering the case of soil plus basal geogrid reinforcement, soil plus ordinary stone column, soil plus encased stone column and finally soil plus encased stone column and basal geogrid the different phases of staged construction developed in plaxis 3d.

4. Discussion and Interpretation of Results

4.1 Interpretation of failure surface

The failure surface for soil only and the different improvement measures are presented in the figure 5 and 6 from these results and other analyzed cases it can be observed that the failure mode of native soil prior to any improvement measures were deep seated failure it was also found from these research that the basal reinforcement below the embankment base has significant impact on the stability of embankment due to even distribution of imposed load of embankment, minimize unequal settlement similarly providing the stone columns cut the failure surface even better way by increasing shear strength, stiffness and densification of the weak soil layer the stone column when get encased provides the better drainage, maintain the permeability without clogging the drainage path and enhance the stiffness and strength of weak soil in so encased stone column in combination with basal reinforcement with optimum center to center spacing value of 2d the failure surface changes from deep seated failure to local /face failure after the improvement measures.

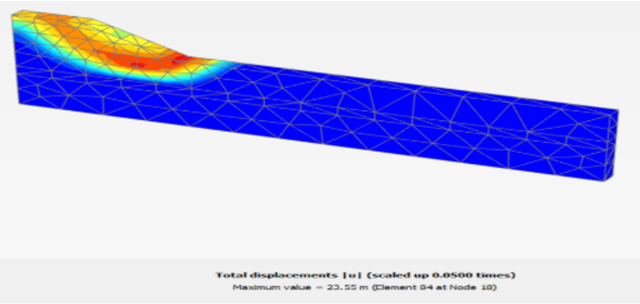

Figure 5: Development of failure surface in case native soil without any improvement measures

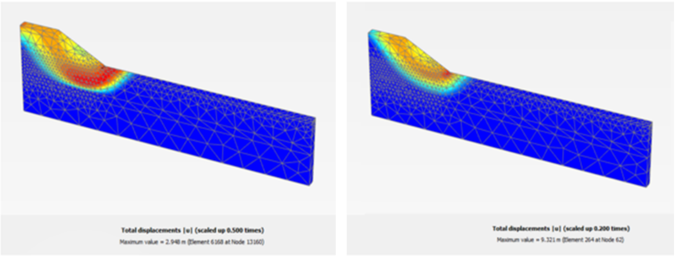

Fig a) Soil+Basal Geogrid

Fig b) With Ordinary Stone Column

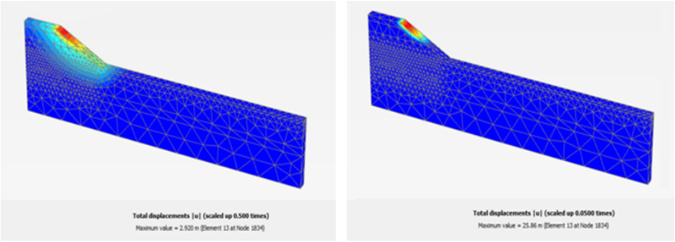

Fig c) With Geogrid Encased Stone Column

Fig d) GECS+Basal Geogrid

Figure 6: The development of the failure mode for varying improvement method a case of 0.8m dia stone column with 2d c/c spacing and geogrid encasement stiffness of 4000 kN/m

4.2 Interpretation of factor of safety

The different FOS(Factor of safety) values for the various stabilization techniques were observed at the toe of the embankment and observed values were displayed. It was discovered that the safety factor in the case of untreated soil, at the end of the monitoring time was 1.17, when utilizing the ordinary stone column this number rises. When the ordinary stone columns get encased with geogrid the factor of safety increased further. The safety factor was increased because of the shearing resistance and restricting support afforded by the GESC lateral bulging and lateral deformation being reduced by geogrid encasing subsequently the stability failure is dependent on the FOS, in our analysis basal reinforcement width is correlated with stone column spacing and stone column spacing is dependent parameter of stone column diameter so higher stone column spacing taken higher will be the basal reinforcement and embankment strip width. The

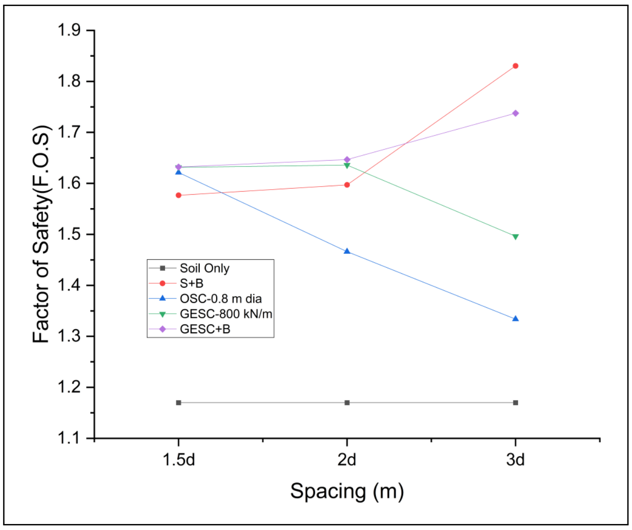

Figure 7: A plot of factor of safety using 0.8m diameter stone column with geogrid encasement stiffness of 800 kN/m at different spacing

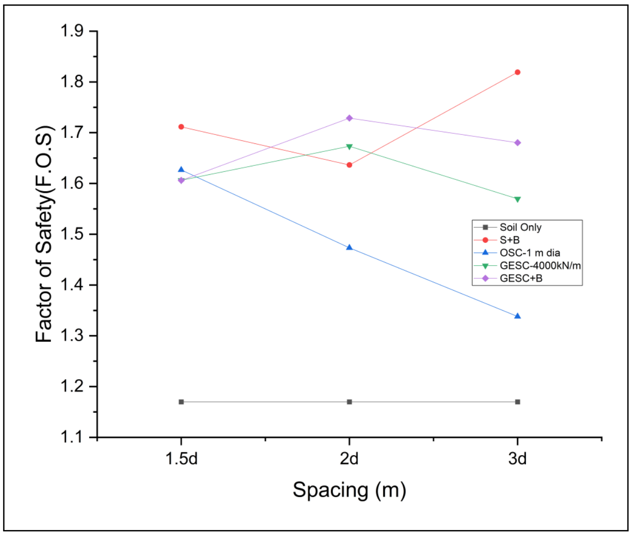

Figure 8: A plot of factor of safety using 1m diameter stone column with geogrid encasement stiffness of 4000 kN/m at different spacing

factor of safety values found increases with an increase in basal reinforcement width because the reinforcement provides additional stability to the embankment by redistributing the load, increased shear strength between the foundation soil and embankment soil and also due to increased friction and tensile strength between soil interface so the effect of basal reinforcement alone or in combination with geogrid encased stones column factor of safety values increased with increase in spacing.

4.3 Interpretation of vertical settlement

The time-settlement curves were used to investigate the performance of the treated soft clay using basal geogrid, stone columns and the geogrid encased stone column the vertical settlement value observed at zero level(0, 0, S) of the embankment. Surface settlement induced by embankment weight was studied at the end of the monitoring period that is after 31 days of start of construction works.As the spacing between the column increases the width of basal reinforcement increases however there seems negligible changes in settlement improvement with increase in spacing these may me due to several reasons such as basal reinforcement primarily functions for preventing shear failure and increase the overall stability of the embankment alternatively it does not directly alter the consolidation process or reduce the compressibility of soil due to the limited influence depth. The maximum value of vertical settlement observed after the analysis found to be 235.92mm in case of native soil without any ground improvement measures it has been found that the ordinary stone columns mainly responsible for minimization of vertical settlement due to densification of loose soil,improved stiffenses enhance drainage in the soil, which reduces the potential for excess pore water pressure build-up, a common cause of settlement and by increasing the bearing capacity of soil wherease the encased stone columns plays singificant role for minimization of vertical settlement due to the aid of tensile strength to the stone columns, enhancing their ability to distribute loads and reduce settlement. The minimum value of vertical settlement found after the geogrid encasement to the stone column coupled with basal geogrid.Higher the encasement stiffness higher the reduction in vertical settlement were recorded.

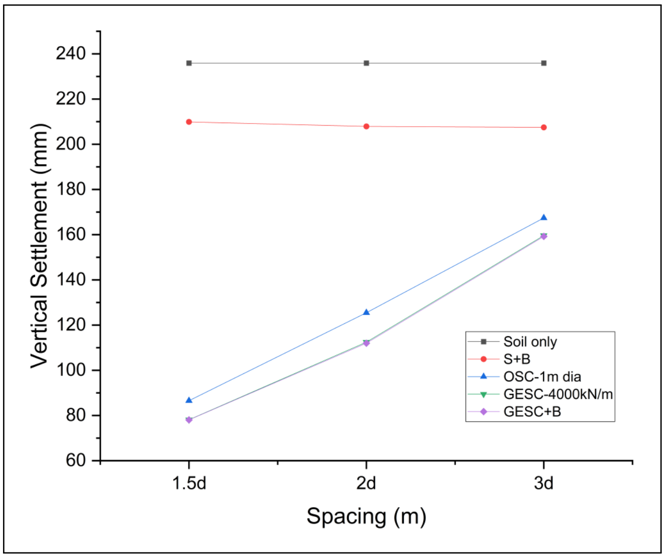

Figure 9: A plot of vertical settlement values using 1 m diameter stone column with geogrid encasement stiffness of 4000 kN/m at different spacing

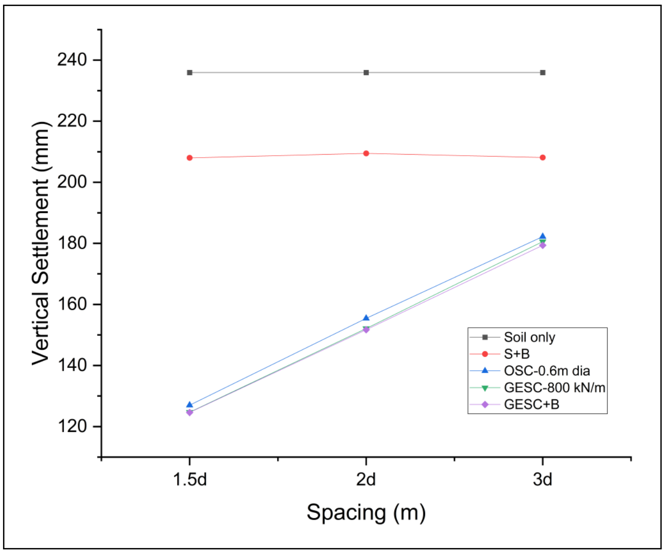

Figure 10: A plot of vertical settlement values using 0.6 m diameter stone column with geogrid encasement stiffness of 800 kN/m at different spacing

4.4 Interpretation of lateral deformation

The lateral deformation value of native soil in the considered point were found to be 176mm at(16.2, 2, 0) and 165.82 at (16.2, 2, 2) and these deformation value found to be 13.8mm and 5.53mm respectively at the top and bottom of the encasement in case of 1m diameter stone column with 1.5d center to center spacing 4000kN/m geogrid encasement stiffness. The lateral deformation value in case of 0.6m diameter GESC with 1.5d spacing and 4000 kN/m geogrid encasement stiffness is also 20.21mm and 20.23mm where the encasement length is 2m, however these research also founds that the maximum bulging of stone column was observed

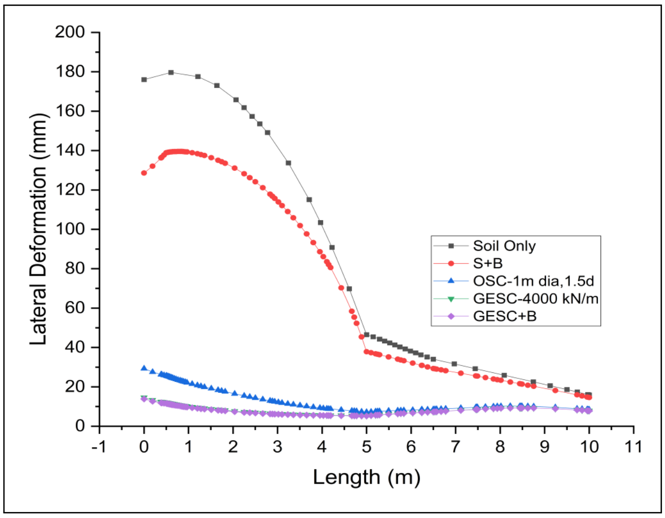

Figure 11: A plot of lateral deformation values versus length in case of 1m diameter stone column with geogrid encasement stiffness of 4000kN/m at spacing of 1.5d

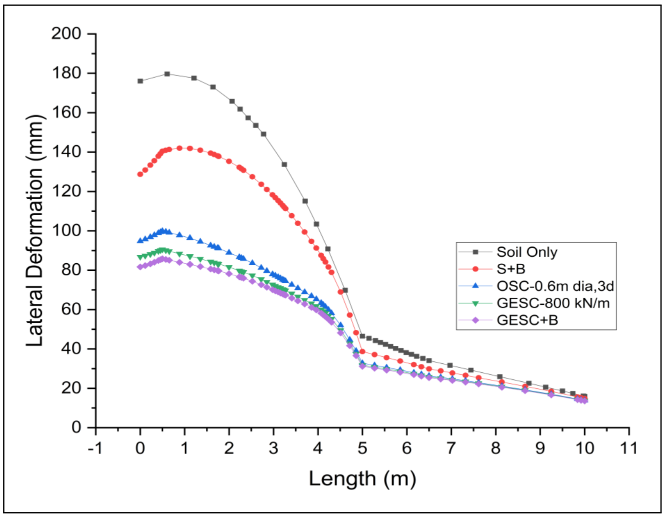

Figure 12: A plot of lateral deformation values versus length in case of 0.6m diameter stone column with geogrid encasement stiffess of 800kN/m at spacing of 3d

close to the column surface and decreased when moving away from the surface this may be because of the increase in lateral earth pressure with depth and the confining pressure, deeper stone column increases the stiffness of soil mass, enhanced shear strength of underlying soil due to the compaction effort during stone column installation, improved bearing capacity of the deeper soils also proves that there will be lesser value of lateral deformation below 5-8 times the column diameter and after that depth there will be no necessary for the providing encasement and even providing stone column.

4.5 Interpretation of total vertical stress

The variation of total vertical stress at the surface of the underlying soil along the embankment width has been observed. The basal geogrid doesn't cope the total vertical stress in significant amount. The surrounding soft soil is no longer stressed due to the construction of stone columns. The material stiffness of the stone columns and the lateral bulging in the ordinary stone column determine how much of the overall stress is conveyed to the soft soil. Compared to the surrounding soft soil, a sizable portion of the embankment load is transferred to the standard stone column. The stone columns' rigidity was increased by encasing them with geogrid, which attracted higher embankment loads than the ordinary stone column. In the figure 13 and 14 it has been seen that in the location where stone column were installed and encased to it there is peak value of stress transferred from native soil and there is the lower value of stress transferred in other case so there is occurrence of intermittent peak in the total vertical stress. The maximum value of total vertical stress shared by geogrid encased stone column found to be 1115.76 kPa at the length of 8m from the left face of embankment in case of 0.8m stone column with 3d spacing with 4000kN/m of geogrid stiffness which is 10 times more than as shared by native soil.

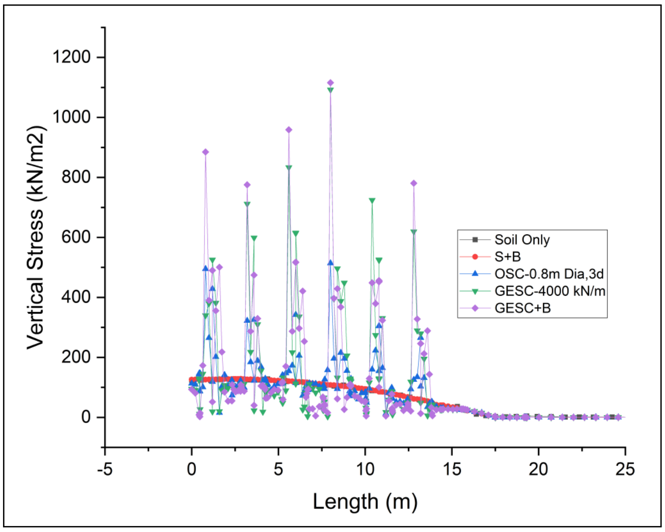

Figure 13: Vertical stress distribution pattern in different improvement methods for 0.8m dia stone column with 3d Spacing for geogrid stiffeness of 4000 kN/m

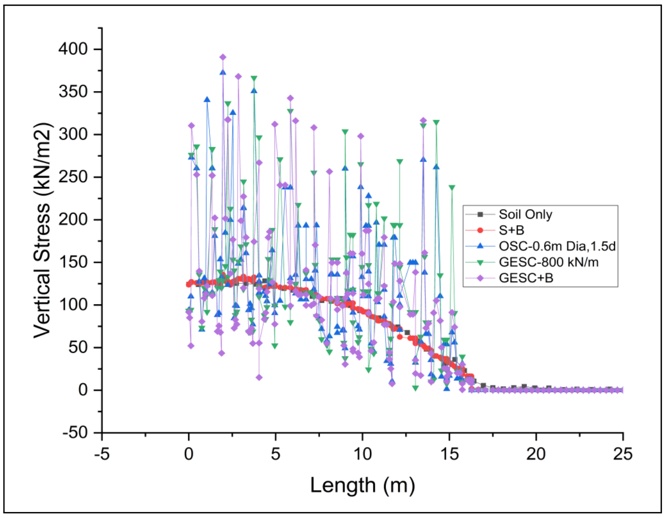

Figure 14: Vertical stress distribution pattern in different improvement methods for 0.6m dia stone column with 1.5d spacing for geogrid encasement stiffeness of 800 kN/m

4.6 Interpretation of excess pore pressure

The excess pore pressure value is observed at the mid of clay layer and found that the value increased during embankment construction and then progressively diminish over time. From the figure15 and 16 it can be observed that the excess pore water pressure generated at the end of the construction period was maximum in case of native soil and it's values found significantly decreased for instance the value of excess pore pressure occurred in native soil are 6.54kPa, 8.74 kPa, 4.28kPa at the end of first stage, second stage and third stage of construction respectively and it reduced to 0.002 kPa, 0.091 kPa, 0.071 kPa at the end of first, second and last stage of construction after the geogrid encasement to the stone column . The installation of the stone columns decreases the amount of embankment total stress transferred to the subsurface, resulting in a drop in the maximal pore pressure, which could be the cause of the fluctuation in the developed pore pressures, furthermore the protective encasement of stone columns enhances their drainage capabilities, reduces clogging, maintains permeability, and ensures stable load transfer these factors collectively expedite the dissipation of excess pore pressure in comparison to ordinary stone columns.

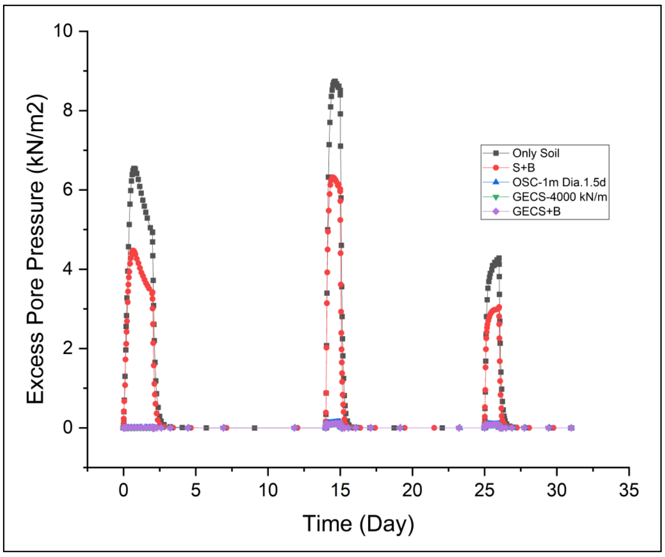

Figure 15: A plot of excess pore pressure at different stage of construction and in different improvement methods for 1m dia, 1.5d, geogrid encasement stiffness of 4000kN/m

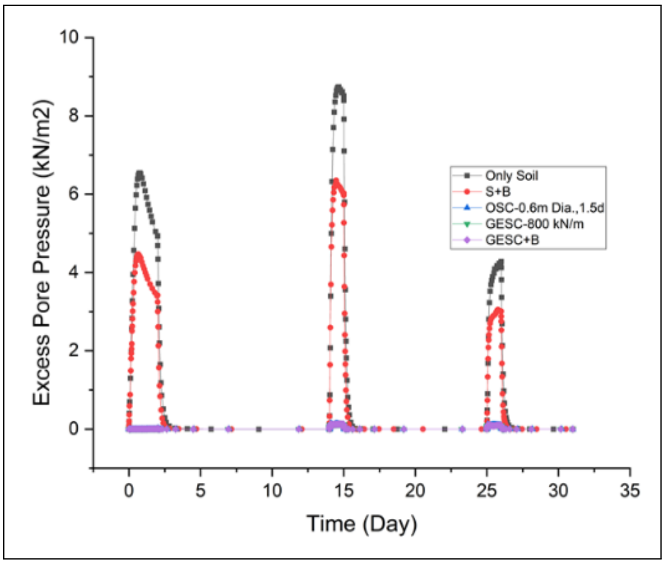

Figure 16: A plot of excess pore pressure at different stage of construction and in different improvement methods for 0.6m, 1.5d, geogrid encasement stiffness of 800kN/m

5. Conclusion

A series of finite element numerical analysis were performed to study the response of the soft soil under the unreinforced, reinforced with basal geogrid, stone column and geogrid encasement in stone columns. Simulations were performed at varying stone column length, diameter, spacing, encasement length and axial stiffness of geogrid and how these parameters influence the favourable benefits for stability of embankment and following conclusion can be made from the study.

- The factor of safety of native soil is found to be 1.17 the value increased by 39% while using ordinary stone column, 48% by using geogrid encased stone column and by 58% geogrid encased stone column in combination with basal geogrid.
- The vertical settlement values decreased with increase in encasement length, stiffness of geogrid encased stone column and increased with increase in center to center spacing between columns the value of vertical settlement get reduced by 67 % (from 235.92mm to 78.05 mm).
- The role of basal reinforcement does not found significant for minimization of lateral deformation, excess pore pressure, vertical settlement and carryover the total vertical stress except for the stabilization of embankment.
- Although the stone column alone is efficient for minimization of vertical settlement,lateral deformation,excess pore pressure and carry the total vertical stress but even better performance can be achieved by using the encasement of appropriate stiffness with minimum spacing in stone columns.

References

[1] Cristian Yair Soriano Camelo. *Three-dimensional numerical analysis of a test embankment on geosynthetic-encased stone columns.* PhD thesis, Universidade Federal do Rio de Janeiro, 2016.

[2] KG Prakash and A Krishnamoorthy. Stability of embankment constructed on soft soil treated with soil–cement columns. *Transportation Infrastructure Geotechnology*, 10(4):595–615, 2023.

[3] KG Prakash and A Krishnamoorthy. Lime-cement columns with pvds for embankment on soft consolidating soil. In *IOP Conference Series: Earth and Environmental Science*, volume 796, page 012030. IOP Publishing, 2021.

[4] Mohamed Saied, Mahmoud M Abu Zeid, and Mostafa A Abdel Naiem. Numerical study of the behaviour of embankment constructed over soft soil stabilized with ordinary and geosynthetic-reinforced stone columns. *JES. Journal of Engineering Sciences*, 50(4):189–204, 2022.

[5] Jorge Castro. Modeling stone columns. *Materials*, 10(7):782, 2017.

[6] MSS Almeida, I Hosseinpour, and M Riccio. Performance of a geosynthetic-encased column (gec) in soft ground: numerical and analytical studies. *Geosynthetics international*, 20(4):252–262, 2013.

[7] S Murugesan and K Rajagopal. Geosynthetic-encased stone columns: numerical evaluation. *Geotextiles and Geomembranes*, 24(6):349–358, 2006.

[8] Soil Test (P) LTD KECC. Soil investigation report (part i - kanchanpur-kamala road). Technical report, Kathmandu, 2018.